Monitoring of the Lower Fraser River Using Fish Assemblages: Can it be done Without Reference Conditions?

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Abstract
Biomonitoring uses the responses of whole communities to environmental changes as an assay of 'undesirable' alterations, relative to some reference condition. Often there are no true references because ecosystems are unique, or comparable reference conditions have been lost, such as for the lower parts of the Fraser River including the estuary. We have sampled the fish assemblages in the lower Fraser River six times over 28 years to detect changes in community structure and to assess if any patterns can be interpreted in terms of food web interactions, or direct effects of the physical and chemical environment. Fish assemblages have shown large differences from year-to-year (up to 3-fold differences in biomass and numbers between years). Large variation in annual reproductive success of species may contribute to shifts in abundance and structure. Several of the 36 species are long-lived (e.g. large-scale sucker) and may archive details on year class strength, which we will need in order to test this source of variation. The absence of detailed understanding of the lower Fraser River's ecosystem challenges our methods available for assessment of ecosystem condition or trend.

Introduction
Most large rivers around the world have enormous values to human societies for water supply, irrigation, transportation, food, and for washing away their various effluents. There are few large rivers that have not been intensively modified for or by some human activity (Dynesius and Nilsson 1994). As large, valuable, and conspicuous ecosystems, most jurisdictions put a large effort into environmental monitoring for these kinds of systems. However, it is never clear what those monitoring efforts should be compared against.

In most scientific endeavours we use some form of control as a reference against which to compare a system of interest (e.g. Reece *et al*.). This is rarely possible for large ecosystems, for which there is no comparable system. For instance, the Fraser River is unlike any other river of the same scale, for reasons of geographic location, parent geology of the basin, its biota, its outflow into the Strait of Georgia and not the ocean, and for many other reasons. The same uniqueness can be claimed for other large ecosystems, including the Columbia or Sacramento Rivers, the Puget Sound, Johnston Strait, just to name some local examples. This problem is therefore not unique to the Fraser River, or to the Pacific Northwest, and is a general one faced by those responsible for protecting the environment in all parts of the globe.

There are a variety of challenges that need to be faced in order to advance our ability to determine the integrity of an ecosystem and to detect subtle signs that may be the vanguard of future changes. Fish are a useful group within the ecosystem for reasons of ease of sampling, certainty of identity, multiple age classes that can "store" useful information about annual and seasonal differences, and a range of sensitivities to their environment. In addition, there is greater public concern over fish than other possible indicators of system condition.

In the absence of suitable measures of the condition and trajectory of the lower Fraser River ecosystem, we are developing an ecosystem model that will incorporate known associations between fish and their physical environment, and interactions within the food web. These models have found extensive application in ecosystems and fisheries modelling elsewhere. In the absence of other means to assess the integrity of the system, this is the primary means left to develop a means of comparing the system's behaviour against model predictions.

Fish provide a useful group of organisms for this analysis and modelling, as they are easier to sample and identify than other ecosystem attributes. As species that are relatively long-lived (relative to benthos or sediment residence times) they can provide information through their size (age) structure about past conditions that help to interpolate for missing information. A reasonable amount of information is available for fish compared to other species in the lower Fraser River. Fish are also slightly more charismatic than benthic invertebrates, and hence public concern is more readily apparent. Finally, they provide a variety of sensitivities and food web positions that aid in construction of an ecosystem model that, they are therefore a tractable component of the river system.

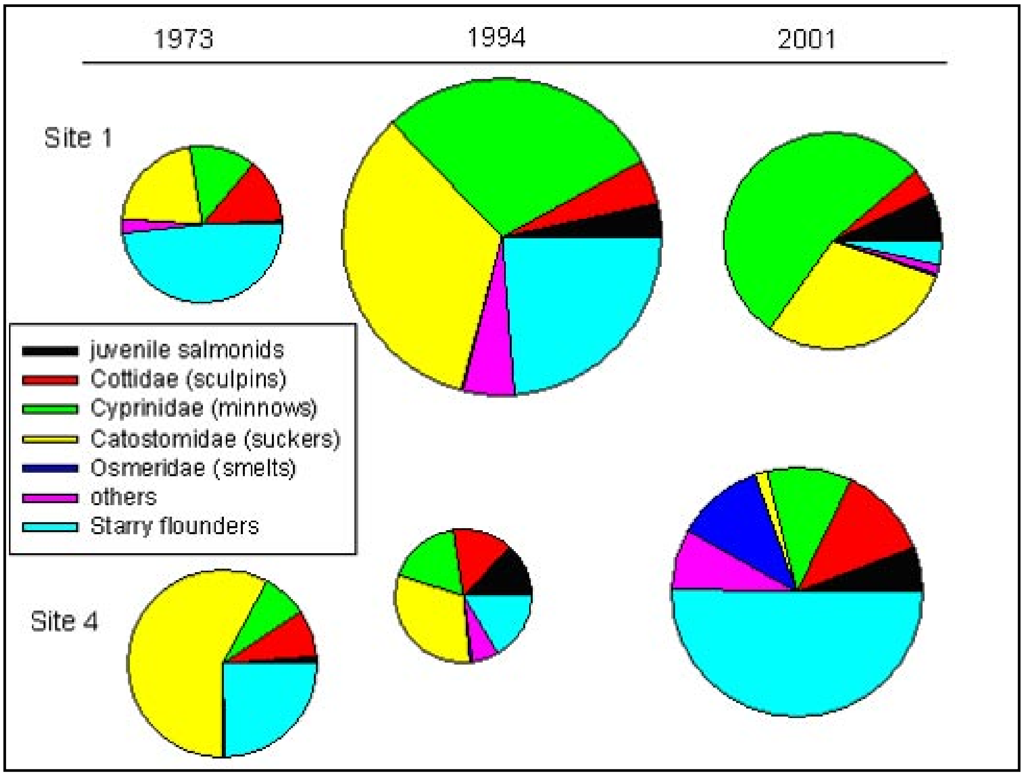

Figure 1. The relative biomass and composition of fish assemblages in the North Arm (site 1) and Main Arm (site 4) of the Fraser River. The sizes of the circles are scaled relative to each other to represent the average biomass in each year and site. The different colours indicate the proportion of the total made up of particular groups of fish species.

Methods and Study Sites

The Fraser River has an average annual flow of approximately 3700 m^3/s at its mouth to the Strait of Georgia. The river has two annual peaks in discharge, one in early summer associated with snowmelt, and the second in early autumn corresponding to the onset of the seasonal rains prior to freezing temperatures around the basin. Its drainage basin encompasses nearly 250,000 km^2, over 99% of which is in British Columbia.

Our sampling design takes advantage of a large sampling effort at 14 sites during the early 1970s (Northcote *et al.* 1978). These sites extend from the end of the river's estuary to about 120 km upstream near Hope, BC. These same 14 sites were again intensively sampled in 1993-1994 (Richardson *et al*. 2000). Of those 14 sites, 3 were selected for continuing study. Those three sites, represented by river reaches of 6 to 10 km length are (1) North Arm from MacDonald Slough upstream to Knight Street, (2) Main Arm from Ladner to Annacis Island, and (3) an aggrading reach of river from the Agassiz Bridge downstream. At each site beach seining using a net of 45.7m length occurred twice a year (April and August). From 10 to 20 sets of the beach seine are made from a boat at each site, and all fish are identified, enumerated, and a sample of them is measured (length and weight). This sampling program has taken place in 4 of the past 10 years and we intend to continue to build up a sufficient time series to determine the status of the river's fish assemblages (see also details at http://faculty.forestry.ubc.ca/richardson/).

Results

In our previously published analysis of the detailed data from 1973 to 1994 we noted some large changes in the composition and biomass of the fish assemblages (Richardson *et al*. 2000). In 1994, the overall biomass per unit area was higher throughout much of the river, but varied across sites. It was also different again in 2001 and 2002 (Figure 1). There are large amounts of variation between years in composition, abundance, and biomass within a site even when those collections are made on the same dates between years.

Discussion

There are many difficulties with using biomonitoring even when there are reference conditions to compare with. Some of the problems faced by biomonitoring are common to our efforts to construct an ecosystem model. For one, these systems are not stationary and are shifting through time in ways that we cannot entirely account for. This problem will affect most monitoring programs. In the case of ecosystem models, these are often parameterised by using time series data, which if the system is not stationary will introduce large errors and a lack of independence in the distribution of error terms of variables incorporated into the models.

In other kinds of biomonitoring the space for time substitution approach may not be justified and is rarely tested by repeated sampling of sites. Related to this is the spatial and temporal autocorrelation that may confound the resolution of these models, but is rarely taken into account. For instance, antecedent conditions can be quite substantial in their impacts on stream communities, but in biomonitoring just become part of the error term reducing its ability to correctly predict outliers.

In some systems it has been possible to reconstruct past conditions through the use of proxy variables to stand in for missing data. One example of this is the now-widespread use of paleolimnological sampling to describe past climates and even the strengths of historic salmon runs, although these are mostly based on lake sediments. One recent attempt to use dedrochronology (size of annual growth-rings of trees) to reconstruct historic salmon runs to rivers in Alaska showed promise (Drake *et al*. 2002). We do not have stands of old-growth trees along the lower Fraser River that could be used in that way, so this proxy variable is not available and would not have contributed information about all the other resident species in the system.

Fish assemblages represent a sufficiently extensive part of the river's food web to reasonably account for most aspects of the river dynamics. The large amount that is known about the biology of fishes and their food web interactions make this a tractable point of departure for an ecosystem model. It is still vital that the time series be sufficiently developed to account for annual variations in year class strengths and account for serial autocorrelation that will be present in any time series, especially for a long-lived set of species. We also know a great deal about the sensitivity of various species, which will enable us to more reliably separate direct environmental effects from indirect effects propagated through food web interactions.

The lack of reference conditions is insufficient grounds to abandon attempts at monitoring of the lower Fraser River ecosystem. This ecosystem is far too valuable to the people of BC for all of its values of biodiversity and amenities. The project is at a point where the time series is getting sufficiently long that we can begin to construct an approximate model, but also at a point where the integrity of the continuous data set could be easily compromised. The next step is to construct a first approximation of the ecosystem model, using well-established principles for model derivation based on years of similar model construction by others. These kinds of models are commonly used in fisheries and other resource management endeavours, and can be easily applied to the lower Fraser situation, once an adequate time series is available to characterise the large amounts of year-to-year variation. Eventually this model will be able to predict particular outcomes from management that can be tested in an adaptive management framework that is not possible at the moment. These quantitative and qualitative predictions can be generated from such a model and new data can be incorporated into the model to refine its predictive abilities.

Acknowledgements

We are grateful for the financial support of this work by the Fraser River Estuary Management Plan, and the Natural Sciences and Engineering Research Council of Canada.

Literature cited

Drake, D.C., R.J. Naiman, and J.M. Helfield. 2002. Reconstructing salmon abundance in rivers: an initial dendrochronological evaluation. Ecology 83:2971-2977.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science, 266:753-762.

Northcote, T.G., N.T. Johnston, and K. Tsumura. 1978. A regional comparison of species distribution, abundance, size and other characteristics of lower Fraser River fishes. Westwater Research Centre Technical Report No. 14, University of British Columbia, Vancouver, BC. 38 pp.

Reece, P.F., T.B. Reynoldson, J.S. Richardson, and D.M. Rosenberg. 2001. Implications of seasonal variation for biomonitoring with predictive models in the Fraser River catchment, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 58:1411-1418.

Richardson, J.S., T.J. Lissimore, M.C. Healey, and T.G. Northcote. 2000. Fish communities of the lower Fraser River (Canada) and a 21-year contrast. Environmental Biology of Fishes, 59:125-140.